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A COMPARISON OF HEART RATE AND OXYGEN UPTAKE RESPONSES TO WORK PERFORMED ON THE TREADMILL AND BICYCLE ERGOMETER

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "A Comparison of Heart Rate and Oxygen Uptake Responses to Work Performed on the Treadmill and Bicycle Ergometer", submitted by Peter Geoffrey King in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The purpose of this thesis was to investigate the hypothesis that significant differences may exist in the heart rate and oxygen uptake responses of several individuals to work performed on the bicycle ergometer and motor-driven treadmill. Specifically, the problem was to determine whether or not maximal heart rate, maximal oxygen uptake, and the heart rate concurrent with a half maximal oxygen uptake differed significantly for work performed on each apparatus. The Astrand-Ryhming nomogram was evaluated in reference to their supposition that ". . . as test work a . . . treadmill test or cycle test may be chosen" (5:221). The experimental group was comprised of twenty subjects who were randomly selected from a finite population of males registered for the first time in the Faculty of Physical Education at the University of Alberta. Approximately equivalent work load increments were initially estimated for both apparati such that any possible effect of procedure on the results obtained might be minimized. Within the limits of the sample tested and the reliability of procedures employed, statistical analysis justified the following conclusions: that significantly higher values of maximal heart rate and maximal oxygen uptake are elicited by treadmill as compared to bicycle ergometer exercise; and that the heart

rate concurrent with a half maximal oxygen uptake does not differ significantly between the two types of apparatus.

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CHAPTER I

STATEMENT OF THE PROBLEM

> The individual's capacity (or fitness) for heavy prolonged muscular work will first of all be dependent on the supply of oxygen to the working muscles. In types of work which engage large groups of muscles the limiting factor for the maximal oxygen intake (aerobic capacity) will probably be the capacity and regulation of the oxygen-transporting system (5:218).

Mitchell *et al* (26:538) state that:

> The maximal oxygen intake which a normal individual can achieve is sometimes taken as an index to maximal cardiovascular function provided pulmonary function is normal. If this concept is sound, the test may come to be of enormous value in the critical evaluation of normal and abnormal cardiovascular function.

The true value of an individual's maximal aerobic capacity at any given moment and under a given set of circumstances may be determined directly, subject to limitations imposed by intra-individual differences and experimental error. In situations where direct determinations are neither feasible nor appropriate, it is suggested (1) that an estimate of maximal oxygen uptake be made from submaximal exercise values by a method such as that proposed by Astrand and Ryhming (5). These authors state that their nomogram is appropriate for exercise performed on either the bicycle ergometer or motor-driven treadmill. While nonsignificant, results published by several investigators (7, 17, 27, 34) suggest possible differences in the maximal

responses elicited by the two types of exercise.

The Problems

It is, therefore, the purpose of this thesis to investigate the hypothesis that significant differences may exist in the heart rate and oxygen uptake responses of several individuals to work performed on the bicycle ergometer and motor-driven treadmill. The specific problems are as follows:

1. To determine whether maximal heart rate and maximal oxygen uptake are significantly different for work performed on the bicycle ergometer and motor-driven treadmill.
2. To determine whether the heart rate concurrent with a half maximal oxygen uptake differs significantly between the two types of apparatus.

A subsidiary problem is as follows:

1. To evaluate the Astrand-Ryhming nomogram in reference to their supposition that ". . . as test work a . . . treadmill test or cycle test can be chosen" (5:221).

A null hypothesis is assumed which states that the mean maximal heart rates, mean maximal oxygen uptakes, and mean heart rates concurrent with a half maximal oxygen uptake are equal for both conditions of exercise (Ho: $U_1 = U_2$).

Limitations of the Study

1. Inference is restricted to the population of males

currently registered for the first time in the Faculty of Physical Education at the University of Alberta.

2. The reliability of the specific testing procedures has not been experimentally established.

3. The temperature and humidity of the laboratory can not be precisely controlled.

4. A response value for a given individual is approximate to the extent of intra-individual variation and experimental error.

Delimitations of the Study

In discussion of the Astrand-Ryhming nomogram, the assumption is made that heart rate and oxygen untake are linearly related throughout the entire range of values. While evidence has been presented (33, 37, 38) that these two parameters may approach their asymptotes at different rates, this paper assumes the former in order to remain consistent with the studies it evaluates.

Definition of Terms

Maximal oxygen uptake. Assuming pulmonary function to be normal, the maximal oxygen uptake is defined as the maximal rate of oxygen supply to and utilization by active tissue.

Aerobic capcity. Aerobic capacity and maximal oxygen uptake are considered to be synonomous.

Steady state. This is defined as a specified period of time during which the demands of exercise are simultaneously satisfied. More specifically, it is a relatively steady state.

Determined maximal oxygen uptake. This is an achieved value of maximal oxygen uptake (also measured maximal oxygen uptake).

Predicted maximal oxygen uptake. The predicted aerobic capacity is an estimate of the determined value made from heart rate response to a submaximal work load (also estimated maximal oxygen uptake).

Submaximal and maximal work load. This concept is individually specific and relative to maximal capacity for a specified period of time.

CHAPTER II

REVIEW OF THE LITERATURE

Astrand-Ryhming Nomogram

The basic nomogram (5) was derived from a linear regression of heart rate on oxygen uptake employing values obtained during exercise on a bicycle ergometer. Mean heart rates at 50 and 70 per cent of aerobic capacity were for men 128 $\pm$ 8--9 and 154 $\pm$ 8--9 beats per minute respectively. The corresponding values for women were 138 $\pm$ 8--9 and 164 $\pm$ 8--9. The mean maximal heart rate was 195 $\pm$ 10. Maximal oxygen uptake as predicted at this value was found to vary with the slope of the heart rate-oxygen uptake curve.

Rowell _et al_ (30:925) stated that:

> If the VO_2 to pulse rate slope is originated at 60 beats/min. and zero VO_2 and then extrapolated through a single value for submaximal VO_2 and pulse rate to a pulse rate of 195 beats/min., the VO_2 at the latter point corresponds exactly to that read from the nomogram as predicted max. VO_2. The pulse rate at 50% of this predicted max. VO_2 will always be 128 beats/min. In this manner, the nomogram of Astrand and Ryhming may be reconstructed.

Wyndham _et al_ (38:927) stated that:

> The simple procedure of Astrand and Ryhming . . . for estimating individual maximum oxygen intake depends upon a criterion that is implied rather than explicitly stated. It is that the maximum level of heart rate and oxygen intake is attained at approximately the same rate of work; hence, if heart rate is plotted against oxygen intake, the relationship should be best represented by a straight line which would hold up to the maximum heart rate. Only if this is the case is it feasible to take

oxygen intake at a heart rate of 128 beats/min. as 'the half maximal O_2 intake' for men, as they propose.

Astrand *et al* (3) specified three pre-requisites of the nomogram. They were as follows:

1. Heart rate and oxygen consumption must be approximately linearly related through a wide range of submaximal values.
2. Prediction must be made from a heart rate of not less than 125 beats per minute.
3. The subject must be able to achieve a maximal heart rate of 195 $\pm$ 10 beats per minute.

An alternate technique (30, 38) for the estimation of aerobic capacity has been the extrapolation of several submaximal heart rate-oxygen uptake points to a known value of maximal heart rate. The difference between values estimated in this manner and those predicted from the nomogram was due primarily to departure of the measured maximal heart rate from 195 beats per minute. Similarly, the two techniques were found to correspond more closely as the heart rate concurrent with a half maximal oxygen uptake approached 128 beats per minute.

Mechanical Efficiency

A constant mechanical efficiency of exercise has enabled prediction of maximal oxygen uptake from submaximal heart rate and work load responses (1, 5, 25). McIlroy (25:680) has defined the efficiency of exercise as ". . . the

relationship between the increase in oxygen consumption due to the work and the external work done". It was stated that for simple large-muscle exercise such as performance on a bicycle ergometer or treadmill, the inter-individual differences in oxygen requirement for a given stress were insignificant. Several investigations have provided further information on the nature of training and intra-individual variation regarding mechanical efficiency. Astrand (3) suggested that for a well-trained subject performing on the bicycle ergometer, the heart rate and oxygen uptake responses were narrowly regulated by the requirements of the task. An approximately 10 per cent improvement in the net efficiency of walking at a fixed grade and rate after two months of training on a treadmill has been reported (23). This improved performance was largely attributed to increased skill in treadmill walking. Taylor et al (34:77) state that ". . . there is good reason . . . to believe that repeated bouts of running on the treadmill result in improved skill for performing the task and reduced oxygen cost". It was also noted that such a phenomenon occurring near the maximal level of work might readily be interpreted as a reduced aerobic capacity when in fact, it represents an improved efficiency. Robinson and Harmon (28) considered efficiency in terms of both aerobic and anaerobic metabolism. Prior to a training period, performance at a near maximal work load

resulted in an average R.Q. of 1.03. Blood lactate levels five minutes following cessation of exercise indicated considerable reliance on anaerobic mechanisms. The degree of anaerobic participation was found to be reduced by a period of training: the mechanical efficiency of running was improved by 8 per cent. Erickson et al (17) attributed a large proportion of improved mechanical efficiency to the psychological adaptation of the subject to the unique factors of an experimental situation.

Astrand and Ryhming (5) specified a submaximal heart rate of not less than 125 beats per minute when predicting maximal oxygen uptake from the nomogram. This has been supported by the conclusion (17:397) that the ". . . energy metabolism of walking is a more stable function at a higher speed and grade".

Taylor (33) reported two principal factors which determine work capacity. The maximal work load which a person can endure for a specified period was found to be linearly related to the sum of efficiency (oxygen consumption at a crest or maximal load per kilogram-meter of work), and maximal oxygen consumption (cubic centimeters per kilogram).

Heart Rate-Oxygen Uptake Relationship

> It is well known that oxygen consumption is a measure of energy expenditure . . . , and that in normal environmental temperatures the heart rate during the steady state of exercise has a relatively linear

relationship to oxygen consumption for a given individual (12:1098).

Wyndham et al (38) have proposed that the assumption of linearity be more thoroughly examined. The literature has variously reported on this phenomenom. Wyndham and Ward (39:385) concluded ". . . that heart rate is a truly linear function of oxygen consumption, and that the oxygen consumption at the maximal heart rates correlates closely with the maximal levels determined by successive increments in the rate of work". Taylor et al (34) also confirmed a linear relationship of heart rate and oxygen uptake to the level of aerobic capacity. In a study of the validity of pulse rate determination of physical working capacity in children (16), oxygen consumption and work load were found to be linearly related to pulse rate values of 210 beats per minute.

It has been firmly established that heart rate and oxygen uptake are linearly related through a wide range of values. The nature and explanation of the relationship at approximately maximal values has not been as concisely defined.

Williams et al (37:628) suggested that ". . . a straight line is a good fit to the data of heart rate/oxygen intake, with a small deviation from the straight line at maximum values of oxygen intake". Data presented by Taylor

(33) indicated a general overall linearity of heart rate versus work load. The trend of these functions on approach to exhaustion levels was found to vary inter-individually. In approximately 40 per cent of the subjects studied by Taylor, there was no deviation of the linear increase of heart rate at maximal levels. The corresponding figure for oxygen uptake was 50 per cent. Of the remaining cases for both parameters, the curves tended to accelerate more often than fall off. Wyndham <u>et al</u> (38:933) have observed that:

> . . . when heart rate is plotted against O_2 intake, the linear relationship, which holds for most of the range of observations, deviates at high levels of work toward O_2 intake values higher than would be predicted from extrapolation of the linear part of the curve to maximum heart rate values and reading off the appropriate oxygen intake values corresponding to the maximum heart rate.

These investigators indicated that when heart rate and oxygen uptake were plotted against work load, the resulting curves had an exponential component at the highest values. The curve for oxygen consumption was found to approach its asymptote more slowly than the curve for heart rate. Therefore, a value for oxygen uptake computed at the point where the heart rate curve approximates its asymptote would underestimate the true maximal oxygen uptake. Two possible explanations for the slower asymptotic approach of oxygen uptake were suggested and are as follows:

1. The hypothesis has been advanced (33, 38) that at maximal levels, the mechanical efficiency of work is reduced thus

necessitating a larger muscle mass and hence, slightly increased oxygen requirement to sustain the effort.

2. An alternate explanation was considered in terms of circulatory parameters (26, 38). Oxygen uptake is dependent upon the product of cardiac output and arteriovenous oxygen difference. Increment in cardiac output beyond a heart rate of 125 beats per minute is due to cardio-acceleration. It should, therefore, follow that an increase in oxygen uptake beyond the maximal heart rate is due to a slight further widening of the arteriovenous oxygen difference. Wyndham _et al_ (38) hypothesized that there is a virtual shutdown of blood flow to certain abdominal viscera and that this flow is diverted to active tissue where the rate of oxygen extraction is greater.

Comparison of Bicycle Ergometer and Motor-Driven Treadmill

> If the aim is to examine the physical work capacity of an individual, the examination should be made DURING muscular work. In such a case it is possible to use submaximal work intensity. Great muscular groups should be engaged in the test work. By this means the oxygen transporting systems can be exposed to a stress without causing local muscular fatigue to be a limiting factor. The work must be technically fairly actively constant, and this efficiency should be fairly high. The work load must be carefully determined and be reproducible. Apparatus that satisfy reasonable demands are the treadmill and the bicycle ergometer (6:324).

The maximal oxygen consumption has been found to be maximal relative to a given set of conditions (26). Taylor _et al_ (34) noted that the amount of muscle mass participating

and hence, the nature of the specific task were instrumental in determining the maximal oxygen uptake. Of several possible means for eliciting a maximal response, the motor-driven treadmill and bicycle ergometer have experienced widest application. A physiological distinction between the two has not been conclusively demonstrated. Without specified proof, it has been stated (1, 17) that a treadmill is to be preferred to a bicycle ergometer. Conversely, it has been suggested (2) that in older subjects, advantages may be attributed to the bicycle ergometer.

The Astrand-Ryhming nomogram has made the assumption that it is applicable regardless of whether the test is performed on a treadmill or bicycle ergometer (30). Validation of this claim (5) yielded small mean differences and no consistent discrepancies between determined and predicted values from exercise performed on either treadmill or bicycle ergometer. Only well-trained subjects were used. Regarding this latter point, Newton (27) has suggested that a trained bicyclist may be able to achieve equal values of aerobic capacity on either apparatus.

Astrand and Saltin concluded (6, 7) ". . . that the aerobic capacity and maximal heart rate are the same in maximal running or cycling, at least in well-trained subjects". It was also noted that a fixed severe work load could be maintained for a longer period of time when the participating

muscle mass was increased. Blood lactate level was identical in both situations, but local concentrations were hypothesized to be greater when a lesser muscle mass performed the exercise. Table I is a partial presentation of their results.

TABLE I

COMPARISON BETWEEN MAXIMAL OXYGEN UPTAKES ELICITED BY THE BICYCLE ERGOMETER AND MOTOR-DRIVEN TREADMILL

Type of work	Mean VO_2 liters/minute	Difference	P
Cycling	4.47	0.22	0.05
Treadmill running	4.69		
Cycling	4.47	0.07	0.5
Treadmill running*	4.54		

*After 1.75--2.75 minutes

Newton (27) has published results which indicate a consistently lower maximal oxygen uptake from work performed on a bicycle ergometer as compared to a standard treadmill run. The bicycle ergometer also produced higher lactate concentrations. It was concluded that ". . . individuals untrained on the bicycle are unable to reach as high a VO_2 on the bicycle as when walking or running on the treadmill at a speed and grade suited to them" (27:169).

Underprediction of Maximal Oxygen Uptake

The capacity to perform physical work can be estimated from study of the pulse rate at submaximal work levels (35). It has not, however, been possible to estimate work capacity from resting heart rate values (11).

Working under the assumption that heart rate and oxygen uptake are linearly related over a wide range of values, Rowell et al (30) compared determined maximal oxygen uptakes with values predicted from the Astrand-Ryhming nomogram for groups of differing physical condition. All data was for treadmill exercise. The nomogram underpredicted determined values by 5.6 ± 4.2 per cent for a group of endurance athletes. For a normal group, underpredictions before and after a training period were respectively 26.8 ± 7.2 per cent and 13.7 ± 7 per cent. Extrapolation of a regression line through several heart rate-oxygen uptake plots to maximal heart rate yielded values different from the nomogram prediction due solely to departure of the measured heart rate from 195. These authors suggested that predicted maximal oxygen uptake would more closely approximate the measured quantity as the heart rate concurrent with a half maximal oxygen uptake approached 128. Similarly, prediction was enhanced as maximal heart rate approached 195 (21). In reference to the prediction of aerobic capacity, Anderson (1:239) has stated that "The variation

coefficient of the direct determination . . . is of the order 3--5%, which is reduced to 15--20% by using the indirect method".

Wyndham *et al* (38) have cited evidence that when heart rate and oxygen uptake were plotted against work load, the curves had an exponential component at maximal values. Since oxygen uptake approached its asymptote more slowly than did heart rate, the value of oxygen uptake at maximal heart rate did not indicate the true aerobic capacity. On this basis, it was hypothesized that the nomogram would consistently underestimate the measured maximal oxygen uptake. This assertion was modified by Rowell *et al* (30:926).

> . . . these estimates are incorrect since Wyndham *et al* were actually assessing the difference between observed max. VO_2 and max. VO_2 estimated by extrapolation of the VO_2-pulse rate slope to observed maximal pulse rate which in their study of four well-trained subjects averaged only 178 beats/min. . . . this procedure does not provide the same value for VO_2 as that obtained from the nomogram since the latter requires extrapolation to 195 beats/min. Contrary to their conclusions, the nomogram should overestimate true max. VO_2. . . . Nevertheless, the criticism by these authors . . . has been borne out in the present study . . . .

Astrand (2:60) has replied that the criticism by Wyndham *et al* was not valid since it was not the premise of the nomogram ". . . that the heart rate is a rectilinear function of oxygen uptake throughout the range of values". It was further stated that the nomogram was empirically constructed from data which included a well-established level

of maximal uptake.

The following sections include information concerning a variety of factors which may produce errors in the prediction of aerobic capacity due to independent variation of submaximal heart rate.

Non-Specific Stress

"It has been recognized for many years, that, over a wide range of submaximal pulse rates or submaximal work loads, there is a large number of physiological conditions which will alter the work pulse rate" (35:704). Similarly, submaximal responses have shown a susceptibility to psychological variations. Taylor et al (35:706) have suggested that "All physiologists who employ submaximal work tests make the tacit but unstated assumption that the stress of work overrides any effect of emotion . . .". The usual maneuver for dissipating psychological stress has been to repeat a procedure on successive occasions such that anticipation is replaced by boredom. Astrand et al (3:258) stated that:

> The criticism, that the results of the usual bicycle ergometer or treadmill test to a high degree may depend upon the mental state of the tested subject, is obviously not valid, at least not if the subjects are trained and the test load is sufficiently high.

It was concluded that under these conditions, physiological responses are narrowly regulated by task requirements and

are highly resistent to psychological variations. Taylor _et al_ (35) have cited evidence that the effects of increased skill in task performance are less than the effects of procedural adaptation. Contrary to the observations of Astrand _et_ _al_ (30:926), it was noted that ". . . very frequently, particularly in physically trained subjects, repeated determinations of submaximal pulse rates are necessary before the rates stabilize and become reproducible at a given work intensity". This has been referred to as a period of "technical training" (17).

It has been well established (3, 11, 29) that emotional factors may markedly influence the resting heart rate prior to a test of work capacity. This phenomenon has been observed in both athletic and nonathletic subjects.

Effect of Heat on Circulatory Parameters

Ambient conditions are capable of exerting a considerable influence over circulatory parameters.

In a study designed to compare the usefulness of oxygen consumption and heart rate as indicators of the strain produced by repetitive work in various environments, Brouha _et_ _al_ (12:1097) reported oxygen uptake to be the more stable of the two functions. Heart rate in heat through successive work periods demonstrated a progressive increase which ". . . reflected a rapidly accumulating strain which

was not apparent from the measurement of oxygen consumption". A second study from this laboratory (13) revealed further that the heart rate response to prolonged submaximal work exhibited no absolute steady state regardless of ambient environment. Information provided on cardiac cost (the sum of work and recovery heart beats beyond the resting level), indicated greater circulatory demands in heat.

Williams _et al_ (37:625) concluded that "In heat the major change in haemodynamics was an increase in heart rate with an associated fall in stroke volume. Neither cardiac output nor arteriovenous difference was significantly altered from comfortable conditions." Maximal heart rate and maximal oxygen uptake were essentially identical in heat and under normal conditions. These phenomena were explained as follows:

> . . . the trend is for heart rate to reach maximum values at lower levels of oxygen intake in heat; and the maximum levels of heart rate, estimated from the asymptotic values, are not significantly different in heat and in comfortable conditions. It follows that because heart rate is increased and the cardiac output unaltered, stroke volume is lower over most of the range of oxygen intakes (37:626).

Cardiac output was shown to be determined primarily by the metabolic rate of working muscle. Vasodilation of peripheral blood vessels during work in heat reduced arteriovenous difference over most of the range of work loads. This was not true of maximal levels, however, as

arteriovenous difference was the same for both conditions. It was hypothesized that the sharp rise in arteriovenous difference at maximum levels signified a shunting of blood from the skin and vicera to working muscle. These conclusions were further substantiated by evidence of significantly higher levels of anaerobic metabolism at lower than normal work loads.

Based on this research, Taylor _et al_ (35:705) have suggested that pulse rate determinations obtained in relatively cool environments ". . . will result in discrimination of differences between individuals in which interfering effects of heat dissipation will be minimized".

Amount of Circulating Haemoglobin

Balke _et al_ (9:235) have cited evidence that "Loss of blood in amounts customary in blood donation imposes significant limitations on physiological adjustments to severe exercise within the first few hours after venesection". Most pronounced among these circulatory alterations was an acceleration of submaximal heart rate during work performed directly following phlebotomy. Oxygen uptake was simultaneously reduced by 9 per cent. Under these conditions, it was hypothesized that corpuscular reduction results in an overcompensation in plasma production. After a recovery period of one week, lower than

normal heart rates were accompanied by a larger stroke volume and oxygen pulse. It was ". . . evident that the cardiovascular system was able to sustain a significantly higher total oxygen intake under these conditions before the test was terminated" (9:237).

Results published by Rowell _et al_ (30) and Taylor _et al_ (35) were not entirely consistent with those presented above. These authors reported that (30:926):

> . . . a 4% decrease in max. VO_2 which followed a 14% decrease in circulating haemoglobin concentration was not accompanied by alterations of submaximal or maximal pulse rates. Accordingly, there was no change in predicted or extrapolated max. VO_2.
>
> Within certain unknown limits which appear to correspond roughly to the normal range the concentration of circulating haemoglobin is not a primary determinant of submaximal or maximal pulse rate or max. VO_2.

Buskirk and Taylor (14) have stated that blood volume was not as closely related to aerobic capacity as was the fat-free body weight. It was suggested that high correlations between blood volume and maximal oxygen uptake were actually dependent upon a close association between blood volume and fat-free body weight.

Maximal Oxygen Uptake and Body Composition

Inter-individual differences in body composition have been shown (14, 36) to account partially for differences in maximal oxygen uptake. Concomitantly, it has been concluded that the efficiency of the respiratory-cardiovascular system

may vary independently of the quantity of active tissue. This latter point was determined to be largely a function of level of conditioning.

Table II presents a comparison of the results published by Buskirk and Taylor (14) and by Welch _et al_ (36:396). The recommendation was made (14:72) that:

> . . . when VO_2 is used to examine the capacity to perform exhausting work the values should be expressed as VO_2 per kilogram of body weight; that when the test is used to examine the performance of the respiratory-cardiovascular system, the values should be expressed as VO_2 per kilogram of fat-free weight.

TABLE II

RESULTS OF CORRELATIONAL ANALYSIS OF MAXIMAL OXYGEN UPTAKE WITH VARIOUS COMPONENTS OF BODY COMPOSITION

Oxygen uptake versus	Correlation coefficient*	
	Welch _et al_	Buskirk and Taylor
Body weight, kilograms	0.59	0.63
Fat-free body weight, kilograms	0.65	0.85
Body weight minus fat minus bone, kilograms	0.64	
Active tissue, kilograms		0.91

*All significant at 1 per cent level of probability

Usage and Limitations of Test Criteria

Mitchell _et al_ (26:539) have reported that:

> Ordinarily the point at which the oxygen intake curve (plotted against work load) ceases to rise was taken as maximal oxygen intake. In most instances (72 per cent), when the work load was increased beyond that producing maximal oxygen intake, the value either remained unchanged or declined. In some cases, however, a relatively slight rise occurred, necessitating the formulation of strict criteria for deciding whether or not maximal, or near maximal, intake actually had been reached.

The criterion established by these investigators was the mean increment in oxygen uptake with each submaximal work load minus twice the standard deviation. It was assumed (26:539) that ". . . the subject had attained his true maximal or had reached the beginning of a plateau and could not increase his intake very much more". This approach was similar to that advocated by Taylor et al (34, 35).

Studies of aerobic capacity have been presented (32, 33) in which motivational factors ultimately determined the level of performance. Of such a criterion, Slonim et al (32) recognized the necessity of arbitrarily defining maximal oxygen uptake as the highest value obtained.

Wyndham et al (37, 38) have criticized the use of precise criteria on the grounds that they fail to account for the slow approach of oxygen uptake to a horizontal asymptote. It was concluded that such a failure introduces a bias toward underestimation of the true maximal oxygen uptake. These authors further commented on the level of

blood lactate as an indicator of metabolic stress. They proposed that while such a state reflects an advancing anaerobic dependence, inter-individual differences in lactate tolerance reduce the criterion to motivational factors. In reply to the first of these criticisms, Taylor et al (35:711) have suggested that while ". . . the work of Wyndham, et al is of real value to our understanding of the max. VO_2", its application is limited due to the large number of determinations necessary in the mathematical formulation of asymptotic values.

Physiological Interpretation of Circulatory Phenomena

This section is intended to briefly elaborate on the basic parameters introduced above and takes the form of the equation (37, 39):

Oxygen consumption (l. per minute) = Heart rate (beats per minute) X Stroke volume (ml. per minute) X A-V difference (ml. per 100 ml. blood)

Heart rate. In a study of the role of vagal tonic inhibitory impulses to the heart, Robinson et al (29:511) indicated that:

> . . . cardio-inhibitory tone is progressively decreased with increasing work stress up to the maximum. Thus, in men, release of the heart by depressing the cardio-inhibitory center probably contributes importantly to the regulation of cardiac acceleration in exercise.

These investigators also reported the existence of an

unspecified central control over excessive heart rates.

Astrand and Ryhming (5) have stated that a value of aerobic capacity predicted from the nomogram is dependent upon the slope of the heart rate-oxygen uptake curve. Hall (20) has made a brief survey of the relevent hypotheses proposed to interpret the relative bradycardia which accompanies repeated heavy exercise. He has noted the fact that current explanations center about a variety of heterogeneous factors and are unable to explain bradycardia as a consequence of an integrated system for adaptation to a high degree of physical stress. The following possibilities were introduced:

1. Increased tonic activity of the cardiac vagus with or without concomitant alterations in sympathetic activity.
2. Increased atrial release of acetylcholine by the trained heart which supplements that released by vagal endings.
3. Cardiac deceleration due to atrial stretch accompanying the general hypertrophy of the heart.
4. Increased muscular strength and possibly reduced reflex discharge from skeletal muscle to circulatory control centers. Also less central or "voluntary" discharge due to relative ease of a given task.
5. Implications of observation that reduced venous pressure due to reduced blood volume invokes sympathetic activity and relative tachycardia.

6. Smaller muscular accumulation of metabolites and less chemoreceptor discharge in trained muscle due to increased capillarization.

Stroke volume and arteriovenous difference. "There is little controversy about the fact that increase in cardiac output and A-V difference both contribute to the increase in oxygen intake up to submaximal levels of work" (37:634). Below oxygen uptakes of approximately 1.0 liter per minute, both heart rate and stroke volume were found to determine cardiac output. At maximal effort, a slight increase in arteriovenous difference accounted for the ultimate level of oxygen intake above the level of maximal heart rate. The data of Mitchell et al which follows was presented to clarify the relative roles of cardiac output and arteriovenous difference in the determination of maximal oxygen uptake.

> Simple increase in cardiac output by 4.3 times, AV oxygen difference remaining at 6.5 ml. per 100 ml., would increase oxygen intake from 340 ml. (resting), to no more than 1,500ml. Widening of the AV oxygen difference by 2.2 times (from 6.5 to 14.3 ml. per 100 ml.), however, permits oxygen intake to exceed 3 liters under the same conditions. Were it not for the ability of the organism to widen its AV oxygen difference, cardiac output would have to increase nearly 10 times to supply 3,200 ml. of oxygen per minute to the tissues (26:543).

Arterial saturation. A possible limitation to the maximal oxygen uptake has been reported by Rowell et al (31). These investigators concluded that a well-conditioned

athlete working at an exhaustion level may experience a minor degree of arterial desaturation. Three mechanisms were suggested which could conceivably have been responsible.

1. Inadequate time for alveolar-capillary oxygen diffusion due to a large cardiac output.
2. Pulmonary arteriovenous shunts during severe exertion.
3. Possible changes in the actual shape of the oxygen dissociation curve.

CHAPTER III

METHODS AND PROCEDURE

Sample

The experimental group was comprised of twenty subjects who were randomly selected from a finite population of males registered for the first time in the Faculty of Physical Education at the University of Alberta. Selection was in the following manner.

1. The population was arranged alphabetically and each member assigned a rank from 1--N.
2. A table of random numbers was employed to draw separate samples of twenty and ten members without replacement.
3. Each member of the larger sample was solicited in order. A refusal was replaced by a subject from the second which was also solicited in order.

Experimental Apparatus

Expired air was directed through a low-resistance triple-J respiratory valve connected by a 1.5 inch flexible hose to a Douglas bag. The respiratory apparatus was comfortably maintained by a light-weight headgear. Samples for oxygen analysis were withdrawn from the Douglas bag via a $\frac{1}{4}$ inch vinyl tube into a Beckman #E-2 oxygen analyser. A #KK Godart Capnograph infra-red carbon dioxide analyser was

employed following the same procedure. Expired air volume was determined by a #802 American Meter Company Gasometer supplied at a rate of 70 liters per minute by a Collins #p-553 1/15 horse power centrifugal pump.

Heart rate was recorded by a Sanborn 100 Viso-Electrocardiogram.

Work Load Determination

Approximately equivalent work loads were determined for bicycle ergometer and treadmill. During the initial phase of experimentation, ten subjects (a separate sample drawn randomly from the population defined above), performed a series of submaximal exercises of both types: performance was on consecutive days and the order of exercise was randomly determined by subject number. Specific procedures were as follows:

Bicycle ergometer. 1. With chest electrodes in place, the subject was given a warm-up of ten minutes duration: 350 and 1200 kpm. for eight and two minutes respectively. (These values had been separately determined to yield heart rates of approximately 100 and 155 beats per minute.) This period was largely intended for procedural adaptation and no determinations were recorded.

2. Work loads were of 900, 1050, and 1200 kilopond meters: 50 pedal revolutions per minute.

3. Exercise was of three minutes duration at each level. A ten minute rest separated exercise periods during which time the subject remained seated on the bicycle.

4. Heart rate was recorded from 2 minutes:45 seconds to 3 minutes.

Treadmill. 1. With chest electrodes in place, the subject was given a warm-up of ten minutes duration: 3.4 and 6 miles per hour at 0 per cent grade for eight and two minutes respectively. (These values had been separately determined to yield heart rates of approximately 100 and 155 beats per minute.) This period was largely intended for procedural adaptation and no determinations were recorded.

2. Performance was at grades of 1, 5, and 9 per cent. Treadmill speed was 6 miles per hour.

3. Exercise was of three minutes duration at each level. A ten minute rest separated exercise periods during which time the subject was seated on a chair placed on the treadmill.

4. Heart rate was recorded from 2 minutes:45 seconds to 3 minutes.

Initial Statistical Analysis

1. A group mean heart rate was determined for each level in both situations. This comprised of individual values as indicated above.

2. A linear regression of work load on mean heart rate was

calculated for both bicycle ergometer and treadmill.

3. Values of work load of both types were predicted at heart rates of 165, 175, 185, 190, 195, 200, 205, 210, and 215 beats per minute.

The extreme upper values were intended to account for any differences present between the initial and experimental samples.

<u>Experimental Procedure</u>

Essentially identical procedures were followed for both the bicycle ergometer and treadmill.

Subjects were requested not to eat for at least three hours prior to testing, not to smoke during the preceding one hour, and to refrain from any unnecessary physical activity beforehand. Each subject was required to appear on two separate occasions. The type of exercise on each occasion for a given individual was determined randomly according to subject number. One day's rest separated the tests. Each subject appeared at approximately the same time of day for both sessions. Specific procedures were as follows:

1. The subject remained seated (either on the bicycle ergometer or on a chair placed on the treadmill), while the basic procedure was explained to him and the necessary apparatus was arranged.

2. With all apparatus in place, the subject was given a warm-up of ten minutes duration: the warm-up was that given for the pilot procedure. This period was largely intended for procedural adaptation and no determinations were recorded.

3. A ten minute rest followed the warm-up and each succeeding exercise period. The subject remained seated either on the bicycle ergometer or on a chair placed on the treadmill.

4. The first work load for all subjects was intended to produce a steady-state heart rate of approximately 165 beats per minute. Thereafter, the step increments were as indicated above. Subjects continued to perform as specified until the second of two consecutive work loads failed to produce an increment in oxygen uptake over the preceding calculation. In the event that a subject was unable to complete a work load, a secondary criterion stated that a value for oxygen uptake would be considered maximal if it differed from the preceding by not more than .054 liters. (see also point 6)

5. Heart rate was recorded from 2 minutes:45 seconds to 3 minutes. Expired air was collected during the last minute of each work phase and analysed during the ten minute rest period. The exact work load for subjects performing on the bicycle ergometer was determined immediately on completion of exercise.

6. When it appeared unlikely that a subject would be able to complete a work load, twenty second gas samples were obtained commencing at 1 minute:20 seconds of exercise. Such partial determinations were considered for criterion purposes. When a subject was unable to complete 1 minute:20 seconds of exercise and had not previously reached a criterion of maximal oxygen uptake, heart rate was recorded after one minute of exercise and the value compared to that for the preceding period. No increase in heart rate was accepted as evidence of maximal performance. "Maximal values" were not accepted at a heart rate of less than 170 beats per minute.

Statistical Analysis (18)

1. A linear regression was fitted separately to the individual data for heart rate and oxygen uptake for bicycle ergometer and treadmill.

2. Group mean values and standard deviations for maximal heart rate and maximal oxygen uptake were calculated from measured individual values.

3. The group mean heart rate concurrent with half maximal oxygen uptake was determined for both situations from individual values as predicted by the regression equations.

4. A t test for correlated samples was applied to test the significance of differences between mean maximal heart rates, mean maximal oxygen uptakes, and the mean predicted

heart rates concurrent with half maximal oxygen uptake in the two types of exercise.

Significance was considered at the .05 level.

Apparatus Calibration

Treadmill. The per cent grade was calculated from the ratio rise over run times 100.

Bicycle ergometer. The sinus balance was calibrated using a set of stainless steel weights. Adjustments were accomplished by altering the center of gravity of the sinus balance.

#802 American Meter Company Gasometer. Accuracy was determined by evacuating several known quantities of gas from a Collins Chain-Compensated Gasometer. Errors were corrected mathematically by a linear transformation.

Gas analysers. Gas analysis apparatus was carefully calibrated prior to each use. Periodic comparisons were also made with results obtained from a Beckman GC2013M gas chromatograph.

Stop watches. Accuracy was determined by comparison with a hundredth-second chronoscope.

Sanborn 100 Viso-Electrocardiogram. Chart speed was determined with a stop watch.

CHAPTER IV

RESULTS AND DISCUSSION

Age, Height, and Weight of Subjects

The means, standard deviations, and ranges of age, height, and weight are given for the pilot and experimental groups respectively, in Tables III and IV.

TABLE III

MEAN, STANDARD DEVIATION, AND RANGE OF AGE, HEIGHT, AND WEIGHT FOR THE PILOT GROUP

Parameter	Mean	Standard deviation	Range
Age (years)	19.3	1.2	18.2--22.2
Height (cm.)	178.5	4.1	170.8--186.1
Weight (kg.)	73.7	6.3	65.7--85.7

TABLE IV

MEAN, STANDARD DEVIATION, AND RANGE OF AGE, HEIGHT, AND WEIGHT FOR THE EXPERIMENTAL GROUP

Parameter	Mean	Standard deviation	Range
Age (years)	19.4	.9	18.3--22.1
Height (cm.)	177.8	5.3	167.0--186.1
Weight (kg.)	76.6	6.5	62.3--88.5

<u>Work Load Prediction</u>

The linear regression coefficients and standard error of estimate for the regression of work load on group mean heart rate response are given in Table V for each of the pilot and experimental groups under both exercise conditions. Values of work load predicted at heart rates of 165, 175, 185, 190, (and 195 for the bicycle ergometer), beats per minute are given in Tables VI and VII. Corresponding regressions of heart rate on work load are presented in Figures 1 and 2: also included are the measured mean responses for the experimental group.

TABLE V

REGRESSION COEFFICIENTS AND STANDARD ERROR FOR THE REGRESSION OF WORK LOAD ON HEART RATE

Group and condition	Slope	X intercept	Standard error of estimate
Pilot--treadmill	.41	-63.73	.18
Experimental--treadmill	.52	-86.92	3.24
Pilot--bicycle	14.10	-1040.11	72.19
Experimental--bicycle	22.30	-2445.20	278.74

TABLE VI

PREDICTED AND MEASURED MEAN HEART RATE RESPONSES TO TREADMILL EXERCISE

Pilot predicted heart rate	Experimental measured heart rate	Pilot predicted % grade	Experimental predicted % grade
165	172.6	3.6	-.8
175	183.9	7.6	4.4
185	190.5	11.7	9.6
190	189.4	13.8	12.3

TABLE VII

PREDICTED AND MEASURED MEAN HEART RATE AND WORK LOAD VALUES FOR BICYCLE ERGOMETER EXERCISE

Pilot predicted heart rate	Experimental measured heart rate	Pilot predicted kpm.	Experimental measured kpm.	Experimental predicted kpm.
165	165.4	1286.4	1262.1	1234.9
175	173.9	1427.4	1409.7	1458.0
185	180.5	1568.4	1553.6	1681.0
190	183.4	1638.9	1629.5	1792.5
195	183.9	1709.4	1704.9	1904.1

FIGURE 1

LINEAR REGRESSIONS OF HEART RATE (Y) ON WORK LOAD (X) FOR THE PILOT AND EXPERIMENTAL GROUPS--TREADMILL

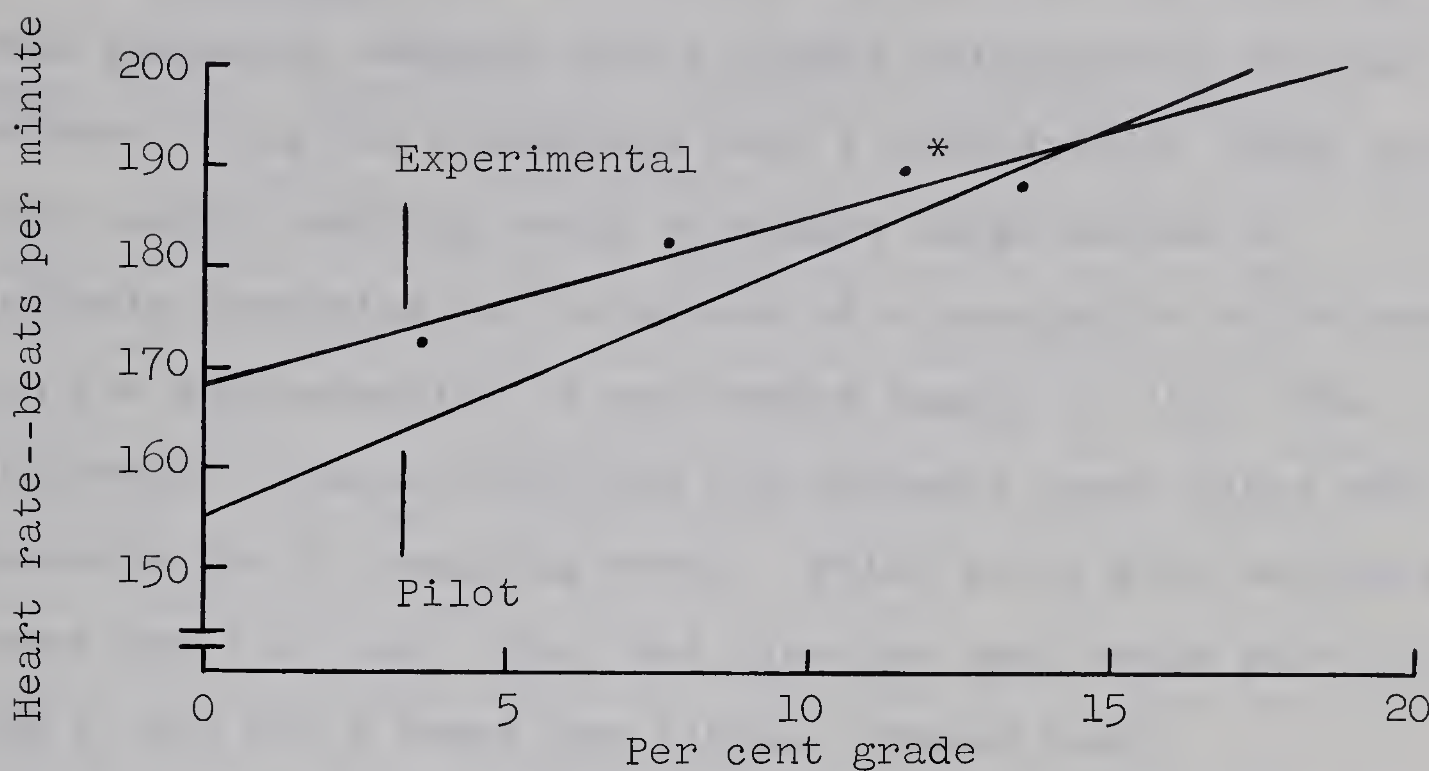
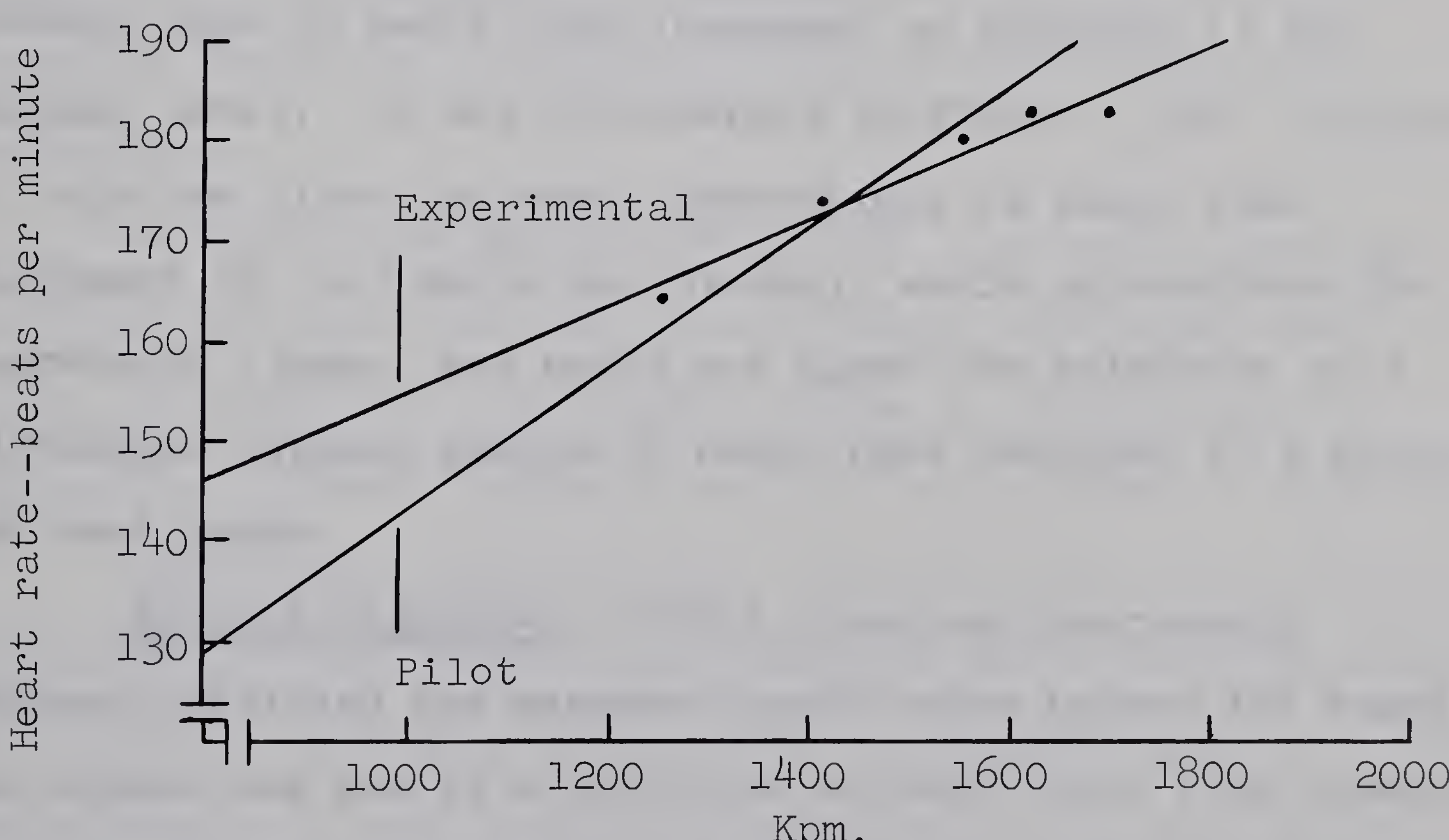
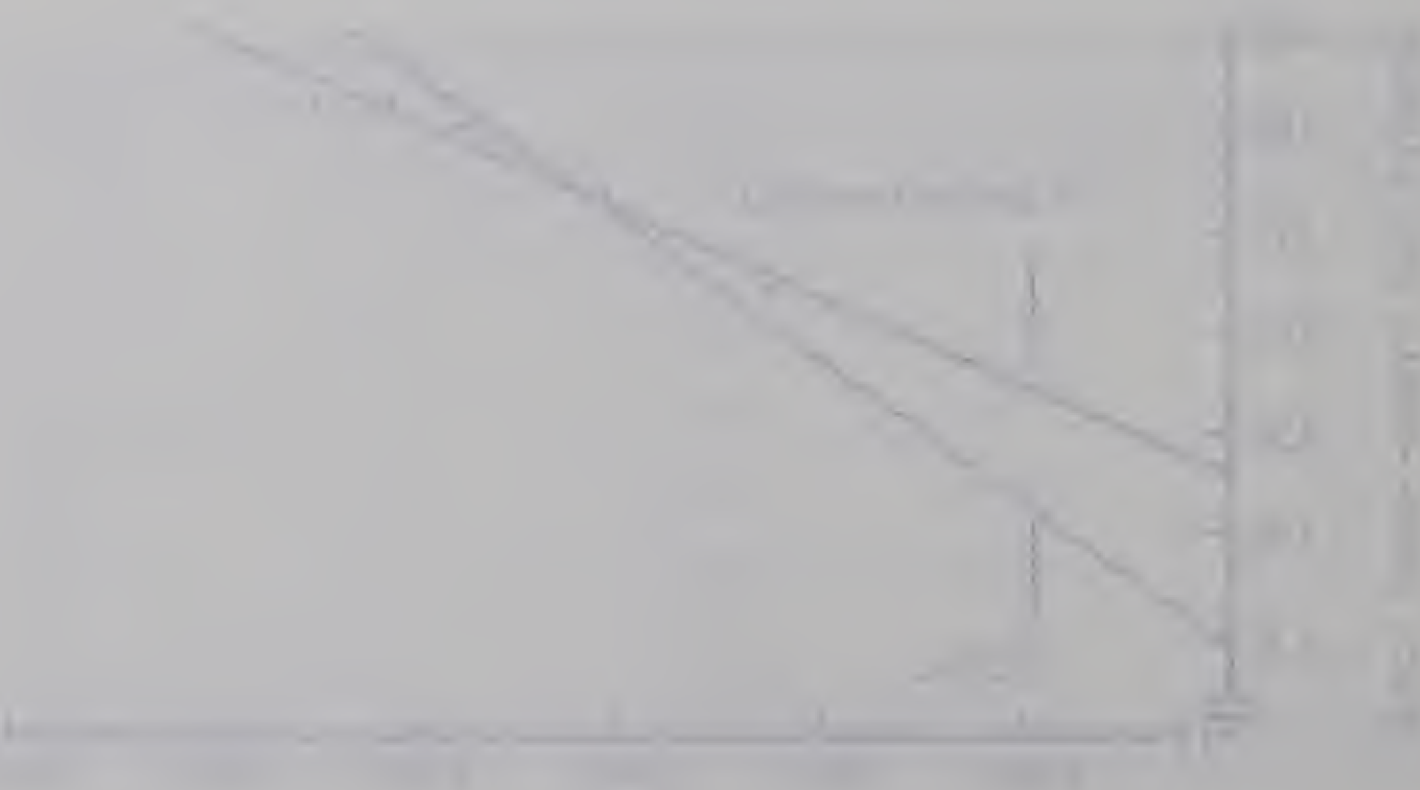


FIGURE 2

LINEAR REGRESSIONS OF HEART RATE (Y) ON WORK LOAD (X) FOR THE PILOT AND EXPERIMENTAL GROUPS--BICYCLE ERGOMETER



*A mean measured response from the experimental procedure



Treadmill. Prediction of work load from mean heart rate responses assumed that a linear relationship existed between these two parameters over a considerable range and that random sampling would eliminate large errors of estimate (assuming the existence of a population relationship and the approximation of any random sample to it). The difference between predicted and measured heart rates was probably due to sampling error. Pilot group mean measured heart rates at one, five, and nine per cent grade were 158.9, 168.2, and 178.5 beats per minute, respectively. Experimental group mean responses to work loads within the range used for the pilot procedure were higher than those measured for the pilot group. The difference in slope between the two regression equations was partly due to a reduced rate of heart rate increment on approach to the maximal level. It may be observed in Figure 1 that inclusion of only the first two mean observations (a heart rate increment of 11.3 beats per minute), would approximate the regression slopes, but would not alter the existence of a difference between groups in heart rate response to a given per cent grade.

Bicycle ergometer. The increasing discrepancy between predicted and measured heart rates beyond 175 beats per minute was due to a deviation of heart rate from linearity toward values less than those expected on the basis of

linear increase in kpm.

Heart Rate, Oxygen Uptake, and Work Load Relationships

A summary of experimental group mean heart rate and oxygen uptake responses to treadmill and bicycle ergometer workloads of increasing severity is presented in Table VIII. Response means are accompanied by their 95 per cent confidence intervals. As work stress was increased, progressively fewer individuals were able to continue. The following discussion of group response characteristics is based on four and five mean observations for the treadmill and bicycle ergometer respectively: the final mean observations are constituted from 70 and 45 per cent respectively, of the initial sample size. Conclusions based on a further reduction of the number of observations per mean would probably introduce interpretive errors due to individual variations.

Based on the data of Table VIII, the relationships between heart rate and work load, oxygen uptake and work load, and heart rate and oxygen uptake are presented in Figures 3, 4, and 5 respectively, for both types of exercise.

Heart rate and work load. As was noted above in the discussion of work load determinations, heart rate for both the treadmill and bicycle ergometer increased in an approximately linear fashion between the first and second

TABLE VIII

MEANS AND 95 PER CENT CONFIDENCE INTERVALS OF HEART RATE AND OXYGEN UPTAKE RESPONSES FOR BOTH APPARATI

Work load no.	N	Heart rate	t.05(S.E.)	Oxygen uptake (l./min.)	t.05(S.E.)	
Treadmill						% grade
1	20	172.6	6.1	3.145	.133	3.6
2	20	183.9	5.0	3.664	.136	7.6
3	20	190.5	3.7	3.896	.151	11.7
4	14	189.4	5.3	4.034	.241	13.8
5	3	194.0	16.3	4.728	1.141	15.8
6	1	184.0	--	5.062	--	17.8
Bicycle						Kpm.
1	20	165.4	6.0	2.800	.087	1262.1
2	20	173.9	5.9	3.158	.089	1409.7
3	19	180.5	5.9	3.440	.137	1553.6
4	17	183.4	6.3	3.493	.236	1629.5
5	9	183.9	7.3	3.845	.204	1704.9
6	5	184.2	15.9	3.879	.360	1749.1
7	1	180.0	--	4.207	--	1912.8

FIGURE 3

MEAN HEART RATE RESPONSES TO BOTH TREADMILL AND BICYCLE ERGOMETER EXERCISE

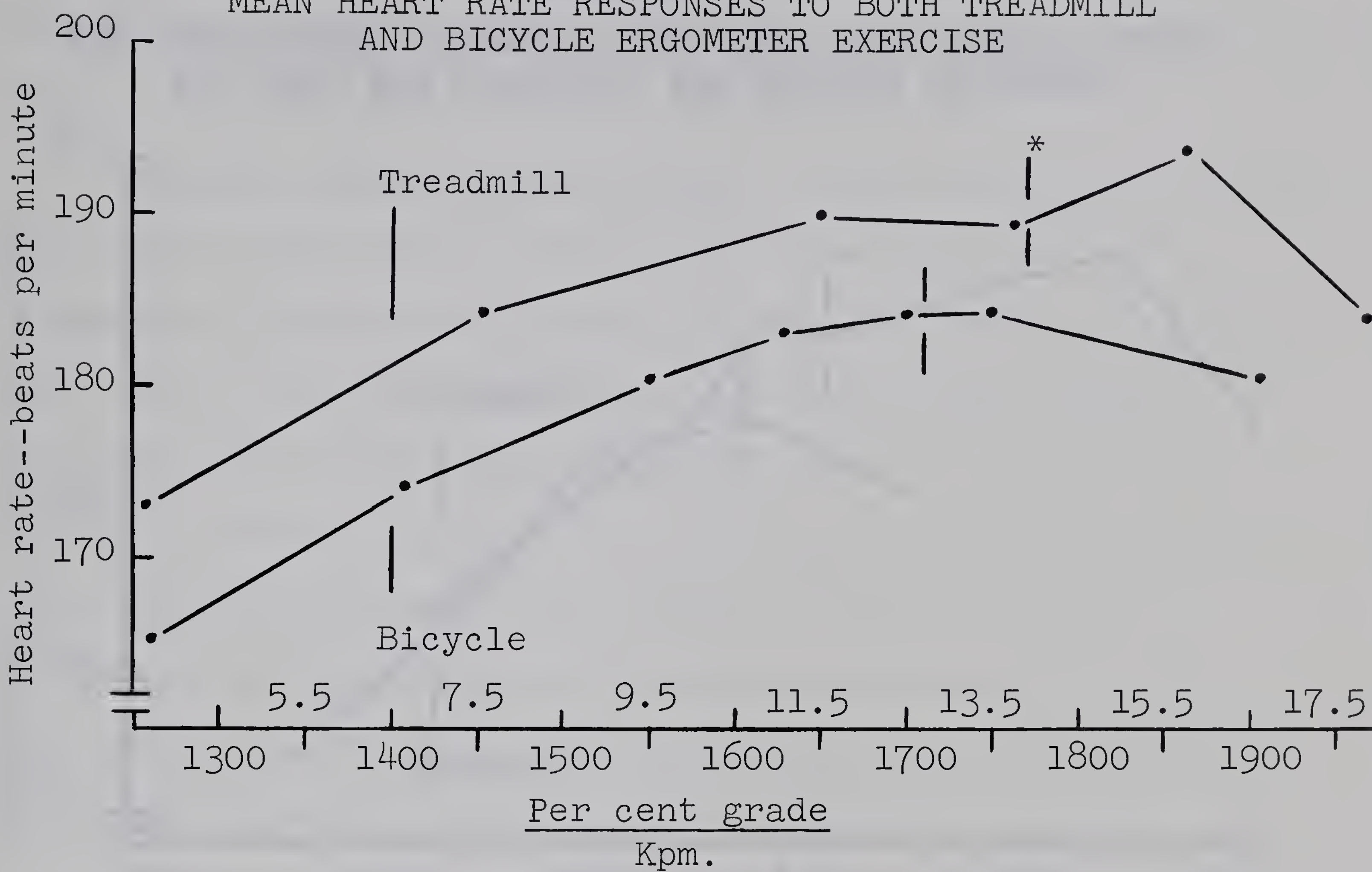


FIGURE 4

MEAN OXYGEN UPTAKE RESPONSES TO BOTH TREADMILL AND BICYCLE ERGOMETER EXERCISE

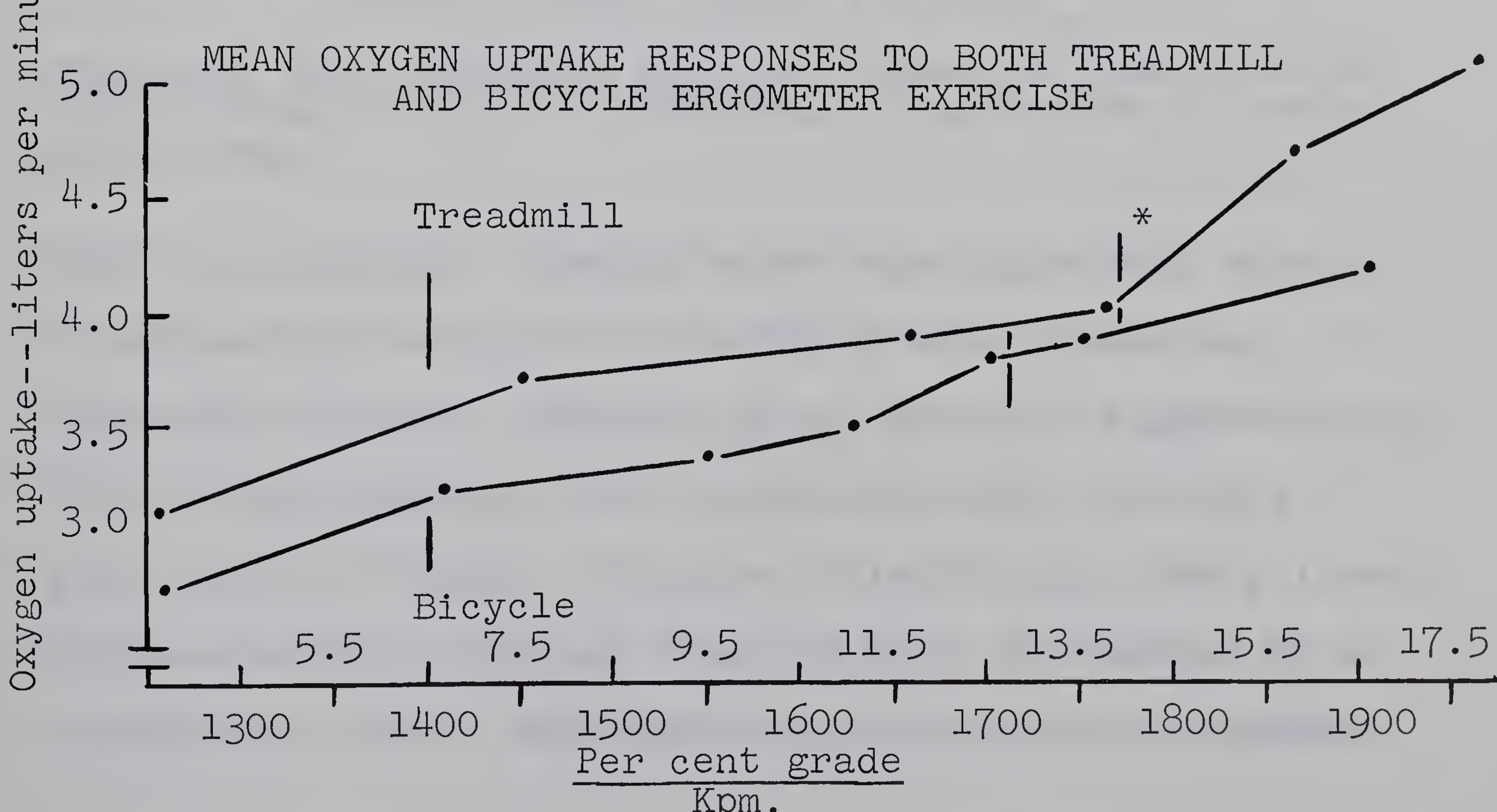
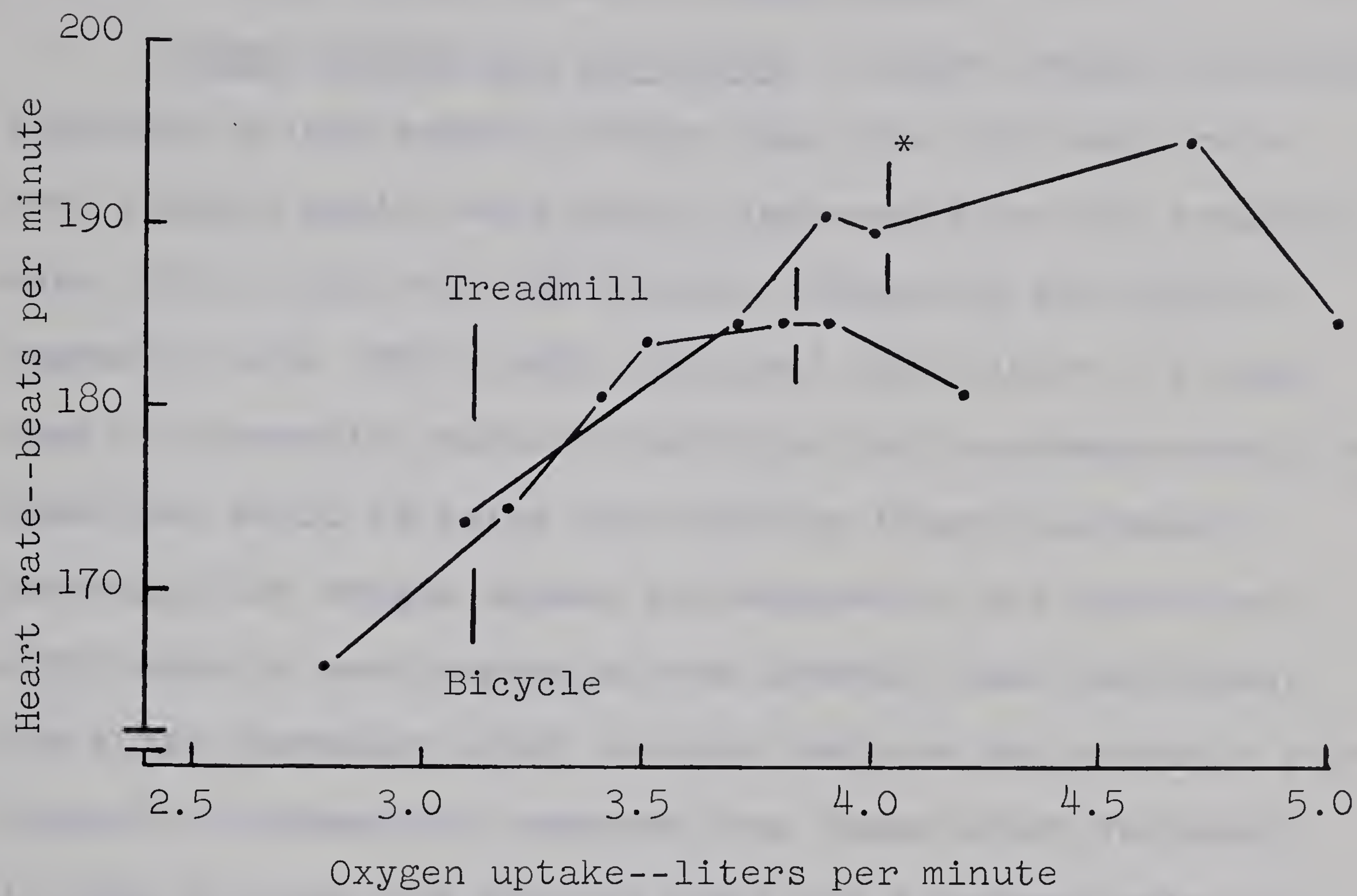


FIGURE 5

THE RELATIONSHIP BETWEEN HEART RATE AND OXYGEN UPTAKE FOR BOTH THE TREADMILL AND BICYCLE ERGOMETER



*Vertical line indicates that the number of observations constituting a point is thereafter insufficient to reflect group trend

mean observations. Further heart rate increments were at a reduced rate while the severity of work stress was increased linearly. Wyndham et al (38) have suggested that while these parameters are linearly related through a wide range of values, deviation of heart rate from a linear increase near the maximal level is best represented by an exponential curve. Mathematical calculation of asymptotic

values was not possible from the present data, but the relationship suggested by these investigators would appear to be more appropriate than a linear model.

Oxygen uptake and work load. Oxygen uptake increments exhibited a less marked pattern than that for heart rate when plotted againt work load. Increments for the treadmill were .519, .232, and .138 liters. Those for the bicycle ergometer were .358, .282, .053, and .352 liters. In the case of linearity, each of the first two increments would be equal and would be twice the third or fourth increment. Assuming that oxygen uptake in response to the first two work loads on each apparatus was narrowly task regulated, the first increment noted in each instance was probably more typical of submaximal response than those which followed. If this is true, the general trend was a reduced rate of increase on approach to the maximal level of work. A notable exception was the fourth increment on the bicycle ergometer. The number of observations constituting the fifth mean response was nine as compared to seventeen on the fourth. Whereas, deletion of eight subjects did not cause a notable alteration in the curve for heart rate response, it did have a considerable effect on the curve for oxygen uptake. A probable explanation resides in the expectation that more fit subjects would have less anaerobic dependence and a greater rate of oxygen uptake than a less fit group at

that which constituted maximal work for the latter. Under the assumption that oxygen uptake increases in a decremental fashion as maximal work load is approached, deletion of less fit subjects could cause a relatively large increase in response curve slope.

Heart rate and oxygen uptake. The mean response relationship between heart rate and oxygen uptake was observed to be approximately linear over most of the range measured for each of the treadmill and bicycle ergometer. A deviation from linearity at the level of maximal response was noted for treadmill exercise such that a slight rise in oxygen uptake occurred with no concomitant rise in heart rate. Wyndham *et al* (38) have reported that when heart rate and oxygen uptake were plotted against work load, the resulting curves had an exponential component at the highest values. The curve for oxygen uptake was found to approach its asymptote more slowly than the curve for heart rate. Two possible explanations for the slower asymptotic approach of oxygen uptake were suggested and are as follows:

1. The hypothesis has been advanced (33, 38) that at maximal levels, the mechanical efficiency of work is reduced thus necessitating a larger muscle mass and hence, slightly increased oxygen requirement to sustain the effort.
2. An alternate explanation was considered in terms of circulatory parameters (26, 38). Oxygen uptake is dependent

upon the product of cardiac output and arteriovenous difference. Increment in cardiac output beyond a heart rate of 125 beats per minute is due to cardio-acceleration. It should, therefore, follow that an increase in oxygen uptake beyond the maximal heart rate is due to a slight further widening of the arteriovenous oxygen difference. Wyndham et al (38) hypothesized that there is a virtual shutdown of blood flow to certain abdominal viscera and that this flow is diverted to active tissue where the rate of oxygen extraction is greater.

A similar occurrence was not clearly observed for the bicycle ergometer. As has been noted, the deletion of eight subjects between the fourth and fifth mean observations caused no alteration in the heart rate curve, but did have a considerable effect on the curve for oxygen uptake. Increment of oxygen uptake beyond that expected on the basis of a linear increase in heart rate may probably be attributed to differences between those subjects who continued and those who terminated after four work loads.

Comparisons Between the Treadmill and Bicycle Ergometer

Maximal heart rate and oxygen uptake. The means and standard deviations of maximal heart rate and oxygen uptake responses to exercise on both the treadmill and bicycle ergometer are given in Table IX. Mean differences and

TABLE IX

MEANS AND STANDARD DEVIATIONS OF MAXIMAL RESPONSES AND PREDICTED HEART RATES*

	Treadmill		Bicycle	
Parameter	Mean	Standard deviation	Mean	Standard deviation
Maximal heart rate	192.5	7.8	187.2	9.3
Maximal oxygen uptake (l./min.)	4.029	.398	3.658	.386
Predicted heart rate*	147.8	20.7	143.5	19.0

*The heart rate coincident with half maximal oxygen uptake was predicted from individual linear regressions.

TABLE X

SIGNIFICANCE OF DIFFERENCES BETWEEN THE TREADMILL AND BICYCLE ERGOMETER

Parameter	Mean difference	d.f.	t
Maximal heart rate	5.3	19	4.267*
Maximal oxygen uptake (l./min.)	.371	19	6.835*
Predicted heart rate	4.3	19	.790

*Significant at .05 level

corresponding t-values between apparati are presented in Table X. Both maximal heart rate and oxygen uptake were significantly higher for treadmill exercise.

A clear physiological distinction between the treadmill and bicycle ergometer with respect to maximal oxygen uptake has not been obtainable from the literature. Without specified proof, it has been stated (1, 17) that a treadmill is to be preferred to a bicycle ergometer although there are occasions (2) when advantages may be attributed to the latter. Newton (27) has published results which indicate a consistently lower maximal oxygen uptake response to work performed on the bicycle ergometer as compared to the treadmill. Conversely, Astrand and Saltin concluded (6, 7) ". . . that the aerobic capacity and maximal heart rate are the same in maximal running or cycling, at least in well-trained subjects". Similarly, blood lactate concentrations were reported to be identical in both situations. While the present data do not include measures of lactic acid, relative exercise severity may be approximately determined from the ventilatory response.

> Anaerobic metabolism causes an accumulation of acid metabolites in the blood, and the lactic acid level rises. This lactic acid is buffered in the blood and as a result extra carbon dioxide is blown off in the lungs. In this situation either the pH must fall or the ventilation must increase or both. In practice, excess CO_2 is blown off in the lungs in response to the increased respiratory stimulus of a fall in pH. (25:681)

If it may be assumed that maximal ventilation volume was not greatly influenced by conscious control, the finding of a non-significant 2.087 liter mean difference favouring the treadmill is indicative of approximately equal stress under both exercise conditions.

Two factors are probably primarily responsible for the lower maximal oxygen uptake observed for the bicycle ergometer: these are a significantly lower maximal heart rate and a smaller participating muscle mass (34). Since oxygen uptake is determined by the product of cardiac output and arteriovenous difference, a smaller cardiac output due to lower heart rate would result in a reduced maximal oxygen uptake (assuming no difference in stroke volume and arteriovenous difference). Similarly, a smaller arteriovenous difference could cause a lower maximal oxygen uptake. This latter point assumes that cycling involves less body mass than treadmill running at an equivalent work load and consequently, that the rate of oxygen extraction is not as great.

The failure of maximal heart rate for the bicycle ergometer to attain the level reached during treadmill exercise may be partially due to pedalling frequency. Carroll (15) has recently reported a significantly higher heart rate for 70 as compared to 50 pedal revolutions per minute at 1000 kpm.

Heart rate concurrent with half maximal oxygen uptake. The heart rate coincident with a half maximal oxygen uptake was predicted for both types of exercise from individual linear regressions: the group means and standard deviations are given in Table IX. Mean predicted heart rates were not found to differ significantly. It is suggested that the data might have demonstrated less variability had more relatively submaximal data been available.

Prediction of maximal oxygen uptake. Astrand and Ryhming in reference to their nomogram, have made the supposition that ". . . as test work a . . . treadmill test or a cycle test can be chosen" (5:221). This supposition is correct only where the treadmill and bicycle ergometer do not yield significant differences in maximal heart rate, maximal oxygen uptake, and heart rate concurrent with a half maximal oxygen uptake. Moreover, prediction more closely approximates the measured quantity as the heart rate concurrent with a half maximal oxygen uptake approaches 128 beats per minute and the maximal heart rate approaches 195 beats per minute.

The present study found that the mean heart rates concurrent with a half maximal oxygen uptake did not differ significantly due to apparatus. Both maximal heart rate and oxygen uptake were, however, significantly different. In each instance, maximal heart rate was less than 195 beats

per minute, but within the required range of 195 $\pm$ 10 beats per minute. On this basis, the nomogram could be expected to overestimate the measured values with greater error occurring for the bicycle ergometer. Overprediction assumes that an increment in oxygen uptake beyond the level of maximal heart rate does not compensate for the discrepancy (38). Glassford et al (19) have reported a significantly higher measured maximal oxygen uptake for treadmill as compared to bicycle ergometer exercise. Aerobic capacity predicted from the nomogram (bicycle ergometer), was not found to differ significantly from the treadmill values, but was significantly higher than that directly obtained for cycling. Maximal exercise on the bicycle ergometer was characterized by a lower mean heart rate than that at maximal levels for the treadmill.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this thesis was to investigate the hypothesis that significant differences may exist in the heart rate and oxygen uptake responses of several individuals to work performed on the bicycle ergometer and motor-driven treadmill. The specific problems were as follows:

1. To determine whether maximal heart rate and maximal oxygen uptake differed significantly for work performed on the treadmill and bicycle ergometer.
2. To determine whether the heart rate concurrent with a half maximal oxygen uptake differed significantly between the two types of apparatus.
3. To evaluate the Astrand-Ryhming nomogram in reference to their supposition that ". . . as test work a . . . treadmill test or cycle test can be chosen" (5:221).

A null hypothesis was assumed which stated that the mean maximal heart rates, mean maximal oxygen uptakes, and mean heart rate concurrent with a half maximal oxygen uptake would not differ due to exercise condition.

The experimental group was comprised of twenty subjects who were randomly selected from a finite population

of males registered for the first time in the Faculty of Physical Education at the University of Alberta.

Approximately equivalent work load increments were estimated during the initial phase of experimentation such that any possible effect of procedure on the results obtained might be minimized. Prediction was based on the mean heart rate responses of ten subjects (a separate sample drawn randomly from the population defined above), to submaximal exercise under both conditions, and assumed that heart rate and work load were approximately linearly related to near-maximal levels.

Conclusions

Within the limits of the sample tested and the reliability of the experimental procedures employed, statistical analysis justifies the following conclusions.

1. Significantly higher values of maximal heart rate and maximal oxygen uptake are elicited by treadmill as compared to bicycle ergometer exercise.
2. The heart rate concurrent with a half maximal oxygen uptake does not differ significantly between the two types of apparatus.

Recommendations

1. A study should be designed to compare submaximal and maximal responses for treadmill walking and running where

increments in severity of exercise for each are determined by per cent grade. Inadequate submaximal data is made available where treadmill speed is six miles per hour and the subjects are relatively unfit.

2. Due to the present finding of a significantly lower maximal response for the bicycle as compared to the treadmill, attention might be directed to Carroll's recommendation (15) of the need to investigate the effect of pedalling frequency on cycling.

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APPENDIX A

STATISTICAL TREATMENT

Linear regression.

$$b_{yx} = \frac{EXY^* - (EXEY/N)}{EX^2 - ((EX)^2/N)}$$

$$a_{yx} = \frac{EY - b_{yx}EX}{N}$$

$$Y^1 \text{ (predicted value of Y)} = b_{yx}X + a_{yx}$$

Correlation coefficient.

$$r = \frac{NEXY - EXEY}{((NEX^2 - (EX)^2)(NEY^2 - (EY)^2))^{.5}}$$

Standard error of estimate.

$$S_{y.x} = S_y(1 - r^2)^{.5}$$

Standard deviation.

$$S = ((EX^2 - \overline{X}^2)/(N - 1))^{.5}$$

t test for correlated data.

$$S_D{}^2 = \frac{ED^2}{N} - \overline{D}^2$$

D = difference between paired observations

$$t = \frac{\overline{D}}{(S_D{}^2/(N - 1))^{.5}}$$

*E = summation

APPENDIX B

INDIVIDUAL DATA SHEET

GAS ANALYSIS COMPUTATION (No. ______)

Name ____________________________

Date ____________________________

Temperature _________ ^{o}C

Barometric Pressure _________ mmHg.

Bicycle _________ kg. X _________ revolutions X 6 = _________ kpm.

Treadmill ___________ %

% O_{2E} = _________ X 2.5 = _________ %

% CO_{2E} = _________ %

% N_{2E} = 100 - _________ % O_{2E} - _________ % CO_{2E} = _________ %

Gas Volume = _______________ liters

V_EATPS (corrected) = ___________ 1.(.984) + .718 = ___________ 1.

(.393 + .984X + .325 liters)

(Conversion to minute volume ATPS = _________ X _________ 1. =

_________ 1./min.

V_ESTPD = _________ (factor) X _________ 1./min. = _________ 1./min.

V_ISTPD = _________ V_ESTPD X $\frac{\qquad}{79.04}$ % N_{2E} = _________ 1./min.

VO_2 consumption = (___________ V_ISTPD X .2093 -

(___________ V_ESTPD X . ___________ O_{2E})

= ___________ 1./min.

VCO_2 production = (___________ V_ESTPD X . ___________ CO_{2E}) -

(___________ V_ISTPD X .0003)

= ___________ 1./min.

APPENDIX C

INDIVIDUAL REGRESSION EQUATIONS

TABLE XI

INDIVIDUAL REGRESSIONS OF HEART RATE ON OXYGEN UPTAKE FOR TREADMILL EXERCISE

Subject no.	Slope	Y intercept	Predicted heart rate*	Standard error of estimate	Heart rate range
1	18.10	117.29	151.6	.93	176--187
2	17.09	101.20	144.5	2.41	155--187
3	17.01	125.35	162.7	2.11	184--200
4	31.70	76.78	132.8	4.17	167--187
5	34.84	76.01	139.1	1.72	180--204
6	37.78	46.55	122.3	2.63	167--195
7	22.19	102.65	149.2	.68	170--195
8	41.08	42.34	119.3	.81	161--195
9	19.35	114.26	152.8	.90	173--191
10	12.20	141.16	165.3	3.69	180--191
11	28.80	68.88	124.7	1.11	155--180
12	15.75	138.29	169.3	.86	180--200
13	28.88	66.40	126.0	1.03	158--187
14	13.61	129.95	163.9	1.63	180--200
15	7.94	165.84	180.6	.41	191--195
16	17.64	110.64	147.6	2.22	155--187
17	16.60	134.25	163.1	1.07	180--187
18	35.53	31.37	101.0	2.47	153--173
19	16.04	134.46	166.4	1.47	191--200
20	15.06	142.71	173.3	.90	191--204

*Predicted heart rate concurrent with a half maximal oxygen uptake

TABLE XII

INDIVIDUAL REGRESSIONS OF HEART RATE ON OXYGEN UPTAKE FOR BICYCLE ERGOMETER EXERCISE

Subject no.	Slope	Y intercept	Predicted heart rate*	Standard error of estimate	Heart rate range
1	16.74	122.64	149.4	1.95	164--176
2	30.88	46.24	113.2	2.80	141--180
3	38.41	45.46	121.6	4.73	164--200
4	5.42	158.81	167.6	.59	173--176
5	27.69	114.29	160.2	3.16	184--204
6	19.83	117.15	153.7	3.99	167--191
7	30.21	79.78	136.9	1.76	158--195
8	50.83	29.38	106.0	2.18	167--184
9	28.36	68.89	125.7	2.38	145--180
10	23.05	104.67	148.5	1.49	170--191
11	4.08	161.51	168.6	4.54	167--180
12	29.86	79.83	134.5	1.44	170--191
13	36.29	50.83	117.8	5.30	150--184
14	14.37	123.42	154.0	2.22	167--187
15	23.40	117.63	158.5	4.10	180--200
16	16.58	104.22	139.5	2.29	155--176
17	16.75	136.51	161.8	--	180--187
18	20.52	87.24	127.9	1.92	145--170
19	22.91	122.25	161.5	.85	184--200
20	16.78	133.76	163.7	3.34	176--191

*Predicted heart rate concurrent with a half maximal oxygen uptake

TABLE XIII

INDIVIDUAL REGRESSIONS OF OXYGEN UPTAKE ON HEART RATE FOR TREADMILL EXERCISE

Subject no.	Slope	Y intercept	Standard error of estimate	Oxygen uptake range (l./min.)
1	.053	-6.076	.050	3.239--3.791
2	.056	-5.411	.137	3.298--5.062
3	.051	-5.895	.116	3.545--4.392
4	.022	-.795	.111	2.962--3.535
5	.028	-2.015	.049	2.970--3.621
6	.025	-.985	.068	3.242--4.011
7	.045	-4.586	.030	3.039--4.198
8	.024	-1.015	.020	2.895--3.745
9	.051	-5.743	.046	3.091--3.989
10	.028	-1.521	.177	3.418--3.950
11	.034	-2.305	.038	3.019--3.879
12	.063	-8.615	.054	2.646--3.931
13	.034	-2.248	.036	3.175--4.129
14	.069	-8.750	.116	3.577--4.984
15	.120	-19.734	.051	3.186--3.728
16	.055	-5.961	.124	2.462--4.194
17	.054	-6.897	.061	3.026--3.478
18	.025	-.425	.066	3.390--3.918
19	.052	-6.445	.084	3.502--3.987
20	.064	-9.005	.059	3.227--4.063

TABLE XIV

INDIVIDUAL REGRESSIONS OF OXYGEN UPTAKE ON HEART RATE FOR BICYCLE ERGOMETER EXERCISE

Subject no.	Slope	Y intercept	Standard error of estimate	Oxygen uptake range (l./min.)
1	.048	-5.351	.105	2.538--3.199
2	.031	-1.281	.089	3.059--4.336
3	.022	-.474	.114	3.104--3.966
4	.153	-23.758	.098	2.682--3.261
5	.031	-3.082	.105	2.550--3.314
6	.039	-3.871	.177	2.596--3.690
7	.032	-2.527	.058	2.630--3.781
8	.018	-.264	.041	2.712--3.013
9	.034	-2.226	.083	2.757--4.010
10	.042	-4.290	.063	2.928--3.808
11	.021	-.595	.325	2.950--3.450
12	.033	-2.494	.048	2.991--3.659
13	.022	-.493	.131	2.766--3.691
14	.062	-7.158	.145	3.115--4.252
15	.030	-2.493	.146	2.769--3.495
16	.056	-5.573	.133	3.003--4.260
17	.060	-8.152	--	2.597--3.015
18	.046	-3.822	.091	2.814--3.962
19	.043	-5.158	.037	2.721--3.427
20	.042	-4.747	.168	2.724--3.565

TABLE XV

INDIVIDUAL REGRESSIONS OF HEART RATE ON WORK LOAD FOR TREADMILL EXERCISE

Subject no.	Slope	Y intercept	Standard error of estimate
1	1.36	171.99	1.21
2	2.08	152.79	4.03
3	1.21	182.44	3.46
4	1.87	161.30	2.53
5	2.96	170.41	1.48
6	2.93	157.36	2.24
7	2.19	163.21	1.80
8	3.37	152.80	4.27
9	1.75	166.66	.11
10	1.36	175.65	.74
11	2.00	151.14	4.67
12	1.84	174.59	1.47
13	2.80	150.60	2.72
14	1.54	174.44	.98
15	.49	189.91	.95
16	3.15	145.89	2.35
17	.86	182.10	1.67
18	1.90	146.82	2.52
19	.49	191.62	3.31
20	.98	189.73	2.81

TABLE XVI

INDIVIDUAL REGRESSIONS OF HEART RATE ON WORK LOAD FOR BICYCLE ERGOMETER EXERCISE

Subject no.	Slope	Y intercept	Standard error of estimate
1	.02	139.30	2.20
2	.07	56.98	3.54
3	.07	80.46	1.45
4	.02	149.07	.32
5	.05	116.00	1.77
6	.06	93.30	1.72
7	.07	75.18	1.80
8	.06	98.57	.94
9	.08	52.98	2.56
10	.05	106.12	2.44
11	.05	100.57	.82
12	.05	105.09	.27
13	.09	28.73	1.09
14	.04	119.21	1.40
15	.04	134.19	1.60
16	.09	38.75	1.85
17	.04	127.78	--
18	.04	90.62	2.13
19	.04	138.16	3.13
20	.03	138.56	.95

TABLE XVII

INDIVIDUAL REGRESSIONS OF OXYGEN UPTAKE ON WORK LOAD FOR TREADMILL EXERCISE

Subject no.	Slope	Y intercept	Standard error of estimate
1	.068	3.075	.113
2	.126	2.965	.097
3	.075	3.316	.126
4	.033	2.908	.162
5	.080	2.745	.089
6	.077	2.941	.026
7	.099	2.723	.059
8	.083	2.678	.087
9	.089	2.723	.048
10	.029	3.452	.195
11	.071	2.845	.149
12	.133	2.341	.141
13	.095	2.928	.108
14	.108	3.325	.117
15	.051	3.115	.158
16	.167	2.103	.249
17	.056	2.852	.038
18	.050	3.285	.080
19	.048	3.426	.137
20	.071	3.069	.138

TABLE XVIII

INDIVIDUAL REGRESSIONS OF OXYGEN UPTAKE ON WORK LOAD FOR BICYCLE ERGOMETER EXERCISE

Subject no.	Slope	Y intercept	Standard error of estimate
1	.001	1.756	.195
2	.002	.547	.161
3	.002	1.250	.100
4	.003	-.562	.144
5	.002	.708	.156
6	.002	-.545	.123
7	.002	-.086	.082
8	.001	1.558	.057
9	.003	-.548	.048
10	.002	.314	.157
11	.001	1.993	.333
12	.002	.909	.040
13	.002	.203	.142
14	.003	-.094	.067
15	.001	1.402	.141
16	.005	-3.836	.029
17	.003	-.521	--
18	.002	.326	.126
19	.001	.955	.164
20	.001	1.138	.179

APPENDIX D

AGE, HEIGHT, AND WEIGHT OF SUBJECTS

TABLE XIX

AGE, HEIGHT, AND WEIGHT
OF PILOT SUBJECTS

Subject no.	Age (years)	Height (cm.)	Weight (kg.)
1	18.5	180.3	65.7
2	19.3	186.1	74.2
3	19.1	175.3	70.4
4	19.1	176.5	83.4
5	18.5	180.3	85.7
6	22.2	182.9	72.4
7	18.3	177.8	66.3
8	19.5	179.7	68.9
9	18.2	175.3	73.8
10	20.5	170.8	76.1

TABLE XX

AGE, HEIGHT, AND WEIGHT OF EXPERIMENTAL SUBJECTS

Subject no.	Age (years)	Height (cm.)	Weight (kg.)
1	19.7	175.9	73.1
2	19.5	186.1	76.6
3	19.5	174.6	81.7
4	19.3	171.5	62.3
5	18.4	167.0	68.3
6	20.7	173.4	76.3
7	19.5	183.5	74.0
8	19.4	177.8	70.6
9	22.1	184.2	87.2
10	18.6	178.4	76.0
11	19.3	177.8	73.2
12	20.0	181.0	70.8
13	18.9	185.4	79.1
14	18.3	175.9	79.1
15	18.5	169.5	87.2
16	20.6	185.4	73.5
17	18.3	181.0	75.3
18	20.1	174.6	83.0
19	19.3	175.3	88.5
20	18.7	177.8	75.5

APPENDIX E

RAW DATA

TABLE XXI

RAW DATA*

Subject no.	Parameter	Work load number 1	2	3	4	5
T1	HR	176	184	187		
	VO_2	3.239	3.751	3.791		
	VCO_2	3.433	4.124	4.525		
	V_E	83.315	102.585	115.429		
B1	HR	164	170	176	173	
	VO_2	2.538	2.944	3.199	2.817	
	VCO_2	2.758	3.238	3.498	2.935	
	V_E	57.210	69.331	92.802	89.748	
	Kpm.	1243.2	1436.6	1600.4	1736.3	
T2	HR	155	173	180	184	187
	VO_2	3.298	4.015	4.521	4.766	5.002
	VCO_2	2.973	3.855	4.773	5.242	5.381
	V_E	61.698	71.805	92.318	107.009	114.009
		(6)				
		184				
		5.062				
		5.479				
		125.384				
B2	HR	141	148	155	161	173
	VO_2	3.059	3.350	3.609	3.605	4.073
	VCO_2	3.065	3.415	3.743	3.801	4.330
	V_E	57.071	63.823	69.970	74.224	90.774
	Kpm.	1252.8	1408.0	1506.2	1539.7	1664.5
		(6)	(7)			
		176	180			
		4.336	4.207			
		4.573	4.320			
		102.318	111.621			
		1707.8	1912.8			
T3	HR	184	195	200	195	
	VO_2	3.545	3.893	4.392	4.201	
	VCO_2	3.838	4.790	5.286	4.227	
	V_E	87.808	107.153	128.279	133.347	

B3	HR	164	173	184	187	195
	VO_2	3.104	3.330	3.650	3.806	3.966
	VCO_2	3.175	3.396	3.739	4.024	4.309
	V_E	71.028	82.440	88.601	94.239	109.933
	Kpm.	1279.3	1399.4	1537.6	1628.2	1768.1
		(6)				
		200				
		3.761				
		4.237				
		142.680				
		1789.7				
B4	HR	173	176	176		
	VO_2	2.682	3.261	3.020		
	VCO_2	2.809	3.560	3.118		
	V_E	62.844	105.637	108.670		
	Kpm.	1294.7	1428.0	1468.6		
T4	HR	167	176	187	184	
	VO_2	2.962	3.181	3.535	3.159	
	VCO_2	2.631	3.324	4.212	3.575	
	V_E	63.095	74.363	98.630	103.041	
B5	HR	184	195	204	204	
	VO_2	2.550	3.001	3.314	3.045	
	VCO_2	3.383	3.694	4.320	3.479	
	V_E	75.674	97.963	124.478	130.312	
	Kpm.	1287.0	1428.0	1600.4	1667.5	
T5	HR	180	195	204		
	VO_2	2.970	3.481	3.621		
	VCO_2	2.955	4.011	4.314		
	V_E	72.603	99.040	114.413		
B6	HR	167	176	180	187	191
	VO_2	2.596	2.949	3.317	3.690	3.343
	VCO_2	2.961	3.392	3.806	4.147	3.978
	V_E	60.172	71.850	91.256	116.178	133.941
	Kpm.	1304.2	1436.6	1578.4	1670.8	1686.1
T6	HR	167	180	195	195	
	VO_2	3.242	3.480	3.845	4.011	
	VCO_2	3.086	3.912	4.754	4.528	
	V_E	69.831	85.608	115.364	155.052	
T7	HR	170	180	191	195	195
	VO_2	3.039	3.501	3.926	4.162	4.198
	VCO_2	2.863	3.521	4.468	4.590	4.684
	V_E	55.927	64.955	78.795	83.160	96.183

B7	HR	158	170	180	187	191
	VO_2	2.630	2.984	3.239	3.538	3.781
	VCO_2	2.529	3.000	3.643	3.926	4.345
	V_E	47.542	51.538	60.505	71.115	90.138
	Kpm.	1253.5	1399.4	1537.4	1615.1	1710.0
		(6)				
		195				
		3.763				
		3.954				
		99.599				
		1814.6				
T8	HR	161	184	195	195	
	VO_2	2.895	3.433	3.695	3.745	
	VCO_2	2.811	3.767	4.343	4.399	
	V_E	64.312	80.664	89.183	113.672	
B8	HR	167	180	184		
	VO_2	2.712	3.013	2.987		
	VCO_2	3.021	3.575	3.555		
	V_E	62.687	81.786	90.689		
	Kpm.	1227.8	1428.0	1537.6		
B9	HR	145	158	170	176	180
	VO_2	2.757	3.141	3.420	3.759	4.010
	VCO_2	2.851	3.401	3.639	3.947	4.242
	V_E	54.095	71.295	83.281	103.281	127.760
	Kpm.	1243.2	1408.0	1515.7	1595.4	1733.9
T9	HR	173	180	187	191	
	VO_2	3.091	3.326	3.326	3.756	
	VCO_2	3.175	3.885	4.536	3.965	
	V_E	70.250	81.434	108.763	121.249	
T10	HR	180	187	191		
	VO_2	3.418	3.950	3.658		
	VCO_2	3.433	4.250	4.513		
	V_E	76.804	90.046	103.267		
B10	HR	170	176	180	191	191
	VO_2	2.928	3.042	3.207	3.808	3.706
	VCO_2	3.111	3.420	3.444	4.163	3.908
	V_E	64.531	74.823	77.914	97.486	111.020
	Kpm.	1320.5	1465.1	1621.4	1692.7	1787.0
B11	HR	167	173	180	176	
	VO_2	2.950	3.276	3.450	2.558	
	VCO_2	3.194	3.646	3.890	3.117	
	V_E	75.702	89.594	106.013	93.879	
	Kpm.	1304.2	1447.1	1548.0	1507.0	

T11	HR	155	170	180	173	
	VO_2	3.019	3.445	3.879	3.633	
	VCO_2	2.898	3.672	4.684	4.138	
	V_E	62.738	80.350	104.776	104.232	
T12	HR	180	191	195	200	
	VO_2	2.646	3.416	3.518	3.931	
	VCO_2	2.357	3.592	4.330	4.679	
	V_E	53.938	76.106	96.869	112.184	
B12	HR	170	176	187	191	
	VO_2	2.991	3.268	3.636	3.659	
	VCO_2	3.105	3.494	4.324	4.052	
	V_E	70.247	85.844	111.706	129.885	
	Kpm.	1243.2	1370.9	1578.4	1647.8	
B13	HR	150	161	173	184	180
	VO_2	2.766	3.221	3.242	3.426	3.691
	VCO_2	2.965	3.283	4.347	3.643	3.657
	V_E	61.512	74.264	97.254	97.931	115.361
	Kpm.	1295.5	1408.9	1558.6	1659.9	1618.7
		(6)				
		180				
		3.575				
		3.509				
		108.970				
		1594.0				
T13	HR	158	176	184	187	
	VO_2	3.175	3.784	4.125	4.129	
	VCO_2	3.101	4.254	5.147	4.096	
	V_E	67.115	91.083	116.456	108.652	
T14	HR	180	187	191	195	200
	VO_2	3.577	4.361	4.565	4.795	4.984
	VCO_2	3.339	4.209	5.130	5.405	5.367
	V_E	71.507	88.242	109.846	118.252	135.165
B14	HR	167	176	180	180	187
	VO_2	3.115	3.517	3.914	4.187	4.252
	VCO_2	2.981	3.614	4.123	4.488	4.480
	V_E	61.194	74.212	90.218	102.707	125.509
	Kpm.	1261.3	1419.4	1569.0	1628.2	1733.9
T15	HR	191	195	195		
	VO_2	3.186	3.728	3.604		
	VCO_2	3.109	4.168	3.858		
	V_E	84.714	109.122	114.471		

B15	HR	180	191	195	200	
	VO_2	2.769	3.121	3.495	3.244	
	VCO_2	2.614	3.176	3.727	3.556	
	V_E	77.549	90.212	104.386	110.425	
	Kpm.	1227.8	1408.0	1609.8	1713.3	
B16	HR	155	161	176	173	
	VO_2	3.003	3.567	4.130	4.260	
	VCO_2	2.830	3.807	4.165	3.795	
	V_E	63.306	88.117	113.475	117.886	
	Kpm.	1287.0	1390.0	1506.2	1515.7	
T16	HR	155	173	184	187	
	VO_2	2.462	3.741	4.143	4.194	
	VCO_2	3.054	3.693	4.831	4.843	
	V_E	70.683	80.795	100.236	107.140	
B17	HR	180	187			
	VO_2	2.597	3.015			
	VCO_2	3.104	3.396			
	V_E	58.332	87.731			
	Kpm.	1166.0	1322.3			
T17	HR	184	191	191		
	VO_2	3.026	3.329	3.478		
	VCO_2	3.548	4.011	3.510		
	V_E	75.969	95.039	109.021		
B18	HR	145	155	158	161	167
	VO_2	2.814	3.230	3.546	3.746	3.787
	VCO_2	2.756	3.674	3.725	4.041	4.099
	V_E	63.077	77.024	84.263	104.406	110.174
	Kpm.	1279.3	1419.4	1484.3	1595.4	1641.6
		(6)				
		170				
		3.962				
		3.876				
		120.376				
		1839.5				
T18	HR	153	161	173	170	
	VO_2	3.390	3.764	3.918	3.886	
	VCO_2	3.289	3.908	4.597	3.680	
	V_E	77.027	88.395	110.238	107.582	
T19	HR	191	200	195		
	VO_2	3.502	3.987	3.896		
	VCO_2	3.668	4.369	4.215		
	V_E	78.557	102.323	121.457		

B19	HR	184	191	200	195
	VO_2	2.721	3.004	3.427	3.114
	VCO_2	3.021	3.299	3.759	2.915
	V_E	70.738	88.685	113.209	98.169
	Kpm.	1253.5	1370.9	1506.2	1595.4
B20	HR	176	184	191	191
	VO_2	2.724	2.932	3.565	3.114
	VCO_2	2.851	3.286	3.876	3.095
	V_E	55.155	67.473	110.124	97.620
	Kpm.	1217.5	1399.4	1653.7	1693.7
T20	HR	191	200	204	200
	VO_2	3.227	3.713	4.063	3.878
	VCO_2	3.152	4.079	4.721	4.451
	V_E	67.498	86.412	110.569	118.060

*HR = minute heart rate
VO_2 = liters of oxygen consumed per minute
VCO_2 = liters of carbon dioxide produced per minute
V_E = volume expired per minute--standard temperature and pressure, dry
Kpm. = kilopond meters per minute